Rec'd PCT/PTO 22 MAY 2001

09/856362

Sughrue
SUGHRUE MION ZINN MACPEAK & SEAS, PLLC

2100 Pennsylvania Avenue, NW
Washington, DC 20037-3213
T 202.293.7060
F 202.293.7860

1010 El Camino Real
Menlo Park, CA 94025-4345
T 650.325.5800
F 650.325.6606

Toei Nishi Shimbashi Bldg. 4F
13-5 Nishi Shimbashi 1-Chome
Minato-Ku, Tokyo 105-0003
Japan
T 03.3503.3760
F 03.3503.3756

www.sughrue.com

David J. Cushing
T 202-663-7925
dcushing@sughrue.com

May 22, 2001

BOX PCT

Commissioner for Patents
Washington, D.C. 20231

PCT/FR00/02637
-filed September 22, 2000

Re: Application of Dominique HAMOIR
AMPLIFICATION FOR VERY BROAD BAND OPTICAL FIBER TRANSMISSION SYSTEMS
Assignee: ALCATEL
Our Ref: Q64544

Dear Sir:

The following documents and fees are submitted herewith in connection with the above application for the purpose of entering the National stage under 35 U.S.C. § 371 and in accordance with Chapter I of the Patent Cooperation Treaty:

- ☑ an executed Declaration and Power of Attorney.
- ☑ an English translation of the International Application.
- ☑ 1 sheet(s) of drawings.
- ☐ an English translation of Article 19 claim amendments.
- ☐ an English translation of Article 34 amendments (annexes to the IPER).
- ☑ an executed Assignment and PTO 1595 form.
- ☑ a Form PTO-1449 listing the ISR references.
- ☑ a Preliminary Amendment

It is assumed that copies of the International Application, the International Search Report, the International Preliminary Examination Report, and any Articles 19 and 34 amendments as required by § 371(c) will be supplied directly by the International Bureau, but if further copies are needed, the undersigned can easily provide them upon request.

PLEASE SEE THE ATTACHED PRELIMINARY AMENDMENT BEFORE CALCULATING THE FEE

The Government filing fee is calculated as follows:

Total claims	20	-	20	=		x	$18.00	=	$.00
Independent claims	2	-	3	=		x	$80.00	=	$.00
Base Fee									$860.00
TOTAL FILING FEE									$860.00
Recordation of Assignment									$ 40.00
TOTAL FEE									$900.00

Sughrue
SUGHRUE MION ZINN MACPEAK & SEAS, PLLC

Checks for the statutory filing fee of $860.00 and Assignment recordation fee of $40.00 are attached. You are also directed and authorized to charge or credit any difference or overpayment to Deposit Account No. 19-4880. The Commissioner is hereby authorized to charge any fees under 37 C.F.R. §§ 1.16, 1.17 and 1.492 which may be required during the entire pendency of the application to Deposit Account No. 19-4880. A duplicate copy of this transmittal letter is attached.

Priority is claimed from September 23, 1999 based on French Application No. 9911875.

Respectfully submitted,

David J. Cushing
Registration No. 28,703

SUGHRUE, MION, ZINN,
MACPEAK & SEAS, PLLC
2100 Pennsylvania Avenue, N.W.
Washington, D.C. 20037-3213
Telephone: (202) 293-7060
Facsimile: (202) 293-7860

Date: May 22, 2001

09/856362
JC18 Rec'd PCT/PTO 22 MAY 2001

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of — PCT/FR00/02637

Dominique HAMOIR

Appln. No.: Not Assigned — Group Art Unit: Not Assigned

Confirmation No.: Not Assigned — Examiner: Not Assigned

Filed: May 22, 2001

For: AMPLIFICATION FOR VERY BROAD BAND OPTICAL FIBER TRANSMISSION SYSTEMS

PRELIMINARY AMENDMENT

Commissioner for Patents
Washington, D.C. 20231

Sir:

Prior to examination, please amend the above-identified application as follows:

IN THE SPECIFICATION:

Please insert the following section headings:

Page 1, after the title, insert the heading:

Background of the Invention

Page 4, before the first full paragraph beginning with "The invention proposes" insert the heading:

Summary of the Invention

Page 5, before the fifth paragraph, beginning with "Other characteristics" insert the heading:

Brief Description of the Drawings

Page 6,the first full paragraph beginning with "The invention is based" insert the following heading:

Detailed Description of the Invention

<u>IN THE CLAIMS</u>:

Please enter the following amended claims:

4. (Amended) The system of claim 1, characterized in that said band extends beyond 1620 nm, preferably beyond 1650 nm, or even more preferably beyond 1670 nm.

5. (Amended)The system of claim 1, characterized in that the compensation means compensate depletion in channels over the beginning of the band.

7. (Amended)The system of claim 1, characterized in that the compensation means compensate enrichment of channels over the end of the band.

9. (Amended)The system of claim 7, characterized in that the compensation means compensate enrichment of the channels over the end of the band by linear losses in the fiber of the transmission system.

10. (Amended)The system of claim 7, characterized in that the compensation means comprise means for emitting lower powers over the end of the band.

14. (Amended)The system of claim 11, characterized in that the compensation means compensate depletion in the channels over the beginning of the band.

16. (Amended)The system of claim 14, characterized in that it comprises distributed amplification means over the beginning of the band.

18. (Amended)The system of claim 16, characterized in that the distributed amplification means comprise rare earth amplification means.

19. (Amended)The system of claim 11, characterized in that the compensation means compensate enrichment of the channels over the end of the band.

<u>IN THE ABSTRACT</u>:

Please delete the present Abstract of the Disclosure and replace it with the following new Abstract of the Disclosure.

ABSTRACT

The invention relates to a very broad band wavelength multiplexed transmission system, typically having a bandwidth greater than 150 nm or 200 nm, and in which energy transfers between channels caused by the Raman effect are compensated. The depletion of channels at shorter wavelengths is compensated by amplification which is preferably distributed, while the enrichment of channels at longer wavelengths is compensated by attenuation.

REMARKS

Entry and consideration of this Amendment is respectfully requested.

Respectfully submitted,

David J. Cushing
Registration No. 28,703

SUGHRUE, MION, ZINN,
MACPEAK & SEAS, PLLC
2100 Pennsylvania Avenue, N.W.
Washington, D.C. 20037-3213
Telephone: (202) 293-7060
Facsimile: (202) 293-7860

Date: May 22, 2001

09/856362

JC18 Rec'd PCT/PTO 22 MAY 2001

APPENDIX

VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE SPECIFICATION:

The specification is changed as follows:

The following section headings were inserted:

Page 1, after the title, insert the heading:

Background of the Invention

Page 4,before the first full paragraph beginning with "The invention proposes" insert the heading:

Summary of the Invention

Page 5,before the fifth paragraph, beginning with "Other characteristics" insert the heading:

Brief Description of the Drawings

Page 6,the first full paragraph beginning with "The invention is based" insert the following heading:

Detailed Description of the Invention

IN THE CLAIMS:

The claims are amended as follows:

4. (Amended) The system of claim 1~~, 2, or 3~~, characterized in that said band extends beyond 1620 nm, preferably beyond 1650 nm, or even more preferably beyond 1670 nm.

5. (Amended)The system of ~~any one of claims 1 to 4~~claim 1, characterized in that the compensation means compensate depletion in channels over the beginning of the band.

7. (Amended)The system of ~~any one of claims 1 to 6~~claim 1, characterized in that the compensation means compensate enrichment of channels over the end of the band.

9. (Amended)The system of claim 7~~-or claim 8~~, characterized in that the compensation means compensate enrichment of the channels over the end of the band by linear losses in the fiber of the transmission system.

10. (Amended)The system of claim 7~~, 8, or 9~~, characterized in that the compensation means comprise means for emitting lower powers over the end of the band.

14. (Amended)The system of claim 11, ~~12, or 13,~~ characterized in that the compensation means compensate depletion in the channels over the beginning of the band.

16. (Amended)The system of claim 14~~-or claim 15~~, characterized in that it comprises distributed amplification means over the beginning of the band.

18. (Amended)The system of claim 16~~-or claim 17~~, characterized in that the distributed amplification means comprise rare earth amplification means.

19. (Amended)The system of ~~any one of claims 11 to 18~~claim 11, characterized in that the compensation means compensate enrichment of the channels over the end of the band.

IN THE ABSTRACT OF DISCLOSURE:

The abstract is changed as follows:

~~ABSTRACT~~

~~AMPLIFICATION FOR VERY BROAD BAND OPTICAL FIBER TRANSMISSION SYSTEMS~~

ABSTRACT

The invention relates to a very broad band wavelength multiplexed transmission system, typically having a bandwidth greater than 150 nm or 200 nm, and in which energy transfers between channels caused by the Raman effect are compensated. The depletion of channels at shorter wavelengths is compensated by amplification which is preferably distributed, while the enrichment of channels at longer wavelengths is compensated by attenuation.

11/PRTS

09/856362

102224/LA/OOCD

AMPLIFICATION FOR VERY BROAD BAND OPTICAL FIBER TRANSMISSION SYSTEMS

The present invention relates to the field of optical transmission, and more particularly to the limitations caused by the Raman effect in optical fiber transmission systems. The invention applies particularly to wavelength division multiplex (WDM) transmission systems.

WDM has made it possible to increase the capacity of optical fiber transmission systems quite considerably. Nevertheless, the Raman effect, or more precisely the crosstalk due to stimulated Raman scattering (SRS) constitutes a major limit; this effect is described, for example, in the work by G.P. Agrawal, entitled "Nonlinear fiber optics", published by Academic Press 1980, for a signal of bandwidth less than or equal to 13 terahertz (THz) (440 cm^{-1}). The effect leads to energy being transferred between the channels. For a WDM transmission system, the Raman effect causes gain to be shifted or the spectrum to be tilted after transmission. In other words, a spectrum presenting a plurality of channels at substantially identical power at the beginning of propagation presents, after propagation and because of the Raman effect, lower power levels for those channels at shorter wavelengths. A known solution to this problem consists in adapting the gain of the amplifiers used. Nevertheless, the range of corrections possible with that solution is limited.

N. Zirngibl, in "Analytical model of Raman gain effects in massive wavelength division multiplexed transmission systems", published in Electronics Letters, Vol. 34, No. 14 (1998), pp. 789-790, proposes a model of the effects of Raman crosstalk showing that the spectral distortion induced by stimulated Raman scattering crosstalk depends only on the total injected power, and not on the spectral distribution of that power. In that article, distortion is modelled by perfect "tilt", and

provision is made for compensation by a linear fiber presenting tilt that is constant in terms of decibels per nanometer (dB/nm).

By way of example, spectrum tilt is described by S. Bigo et al. in "Investigation of stimulated Raman scattering on WDM structures over various types of fiber infrastructures", published as an OFC'99 paper WJ7, February 21-27, 1999. That document measures the effects of Raman crosstalk in the wavelength range situated around 1550 nm, but it does not propose any solution to the problem.

D.N. Christodoulides and R.B. Jander in "Evolution of stimulated Raman crosstalk in wavelength division multiplexed systems", published in IEEE Photonics Technology Letter, Vol. 8, No. 12, December 1996, pp. 1722-1724, proposes a digital simulation of the crosstalk caused by the Raman effect between the various channels of a WDM transmission system. That document uses a triangular approximation to the Raman gain profile over the multiplex.

A.R. Chraplyvy in "Optical power limits in multi-channel wavelength division multiplexed systems due to stimulated Raman scattering", published in Electronics Letters, Vol. 20, No. 2 (1984), pp. 58-59 also proposes a triangular approximation for Raman gain in a WDM transmission system; it is specified that the models provided in that document can be used for estimating the limitations induced by crosstalk due to the stimulated Raman effect. That document does not propose a solution to the problems raised by such amplification.

A single coherent light wave emitted into a monomode fiber is subjected to losses associated with spontaneous generation of a second wave, and then to it being amplified, because of the Raman effect. The frequency of the resulting wave is reduced by about 13 THz relative to the initial wave. T. Sylvestre et al. in "Stimulated Raman suppression under dual-frequency pumping in single

mode fibers", published in Electronics Letters, Vol. 34, No. 14 (1998), pp. 1417-1418 describes an experimental setup enabling these loses to be greatly limited for the wave of interest by eliminating the resulting wave. To do this, a wave whose frequency is about 2 × 13 THz less than the frequency of the wave of interest is also emitted into the fiber, and a polarization-maintaining fiber is considered. That method of reducing the Raman effect is not applicable to a broad band or a very broad band transmission system.

The French patent application filed on June 10, 1999 under the No. 99/07324 and entitled "Compensation de l'effet Raman par pompage dans un système de transmission à multiplexage en longeur d'onde" [Raman effect compensation by pumping in a wavelength division multiplexed transmission system], proposes injecting pumps at wavelengths lower than those of the signals of a wavelength division multiplex into a link in order to compensate for the tilt caused by the Raman effect on the channels of the multiplex. The energy provided by the pumps compensates for the losses from the initial channels of the multiplex. That solution is proposed for signals at wavelengths lying in the range 1520 nm to 1600 nm, i.e. over bandwidths that are generally less than 80 nm to 100 nm, and that are at most equal to 20 THz.

All of those documents of the state of the art, and also the last-mentioned French patent application, apply to a transmission band centered around 1550 nm, i.e. to wavelengths in the range 1520 nm to 1600 nm.

Kenneth L. Walker in "Status and challenge of optical amplifiers and lasers", published at OAA'98, MB1, pp. 12-14, mentions as a future development the use of the entire spectrum width that is available in optical fibers, i.e. bandwidths of 400 nm or even more in the range 1.2 micrometers (μm) to 1.7 μm. That document specifies that the two main factors which limit the use

of the entire spectrum available in a fiber are dispersion and attenuation. It further states that Raman amplification constitutes a good candidate for amplification over a broad band, unlike rare earth doped amplifiers which operate only over a bandwidth of less than 100 μm. To ensure gain flatness, that article proposes using long-period gratings as a filter; the examples proposed show filters in the range 1500 nm to 1600 nm and the resulting gain over a bandwidth of 40 nm.

The invention proposes a solution to the novel problem of the distortion caused by the Raman effect over very broad bandwidths. In the present specification, the term "very broad band" is used to mean wavelength ranges that extend over more than 150 nm or more than 200 nm, i.e. over more than 20 THz or more than 30 THz.

The invention is based on the observation that the Raman effect over such bandwidths generates distortion by crosstalk between the various channels. This distortion modifies the spectral energy distribution in a manner that is quite different from that already known in the context of narrow band transmission, as mentioned above. These new modifications to spectral distribution must be corrected in order to make transmission possible.

The invention proposes a solution to this new problem.

More precisely, the invention proposes a very broad band wavelength division multiplex transmission system with means for compensating energy transfers between channels caused by the Raman effect. The system presents a bandwidth greater than 20 THz, or indeed greater than 30 THz.

In an embodiment, the bandwidth extends to above 1620 nm, preferably to above 1650 nm or even more preferably to above 1670 nm.

Advantageously, the compensation means compensate for depletion in the channels at the beginning of the

band, e.g. over a bandwidth lying in the range 13 THz to 21 THz.

The compensation means can also compensate for enrichment of the channels towards the end of the band, for example over a bandwidth lying in the range 13 THz to 21 THz. In an embodiment, the compensation means compensate for enrichment of channels towards the end of the band by inserting linear losses into the fiber of the transmission system. The compensation means can thus comprise means for emitting lower powers towards the end of the band.

The invention also provides a very broad band optical amplification system including compensation means for compensating the energy transfers that are caused by the Raman effect. The bandwidth is preferably greater than 20 THz, or indeed greater than 30 THz.

Advantageously, the compensation means compensate depletion in the channels towards the beginning of the band, e.g. over a bandwidth lying in the range 13 THz to 21 THz. For this purpose, it is possible to provide distributed amplification means over the beginning of the band. By way of example, these means comprise Raman amplifier means and/or rare earth amplifier means.

In an embodiment the compensation means compensate enrichment of the channels towards the end of the band, e.g. over a bandwidth lying in the range 13 THz to 21 THz.

Other characteristics and advantages of the invention will appear on reading the following description of embodiments of the invention, given by way of example and made with reference to the accompanying drawing, in which:

· Figure 1 is a diagrammatic graph showing how spectrum distribution is modified by the Raman effect in a very broad band transmission system; and

· Figure 2 is a diagrammatic graph showing the appearance of gain for amplification in a very broad band transmission system.

The invention is based on the observation that the distortion caused by the Raman effect in very broad band systems is different from the distortion caused by the same Raman effect in conventional WDM transmission systems. As a result, the appearance of the distortion obtained is completely different, see for example the article by S. Bigo et al., which mentions only one tilt, in other words an effect which can be approximated by a straight line of positive slope.

In addition, solutions such as the presence of pumps at wavelengths below those of the multiplex, for example, as proposed in the above-mentioned patent application, can provide compensation only over a few tens of nanometers, and at most over 20 THz.

The invention thus proposes generic compensation of Raman gain effects in very broad band transmission systems.

Figure 1 is a diagrammatic graph of modifications to the spectral distribution caused by the Raman effect in a very broad band transmission system. Wavelength is plotted in nanometers or in terahertz along the abscissa. Power is plotted in dB up the ordinate. The figure shows the modifications caused by the Raman effect on channels in a multiplex that extends over the range 1200 nm to 1700 nm. The bold line in the figure shows constant power distribution for the various channels of the multiplex, which is the intended result. Dashed line curves show qualitatively the appearance of the departures from this ideal distribution caused by the Raman effect. The graph of Figure 1 reveals essentially three different zones. A first zone extends from the beginning of the available bandwidth, from 1200 nm or 250 THz, over a wavelength range of about 13 THz or about 85 nm, and more generally over a range having a bandwidth

of 13 THz to 21 THz. In this first zone, the channels of the multiplex are subjected to depletion by the Raman effect, to the advantage of channels of longer wavelength. Their power is thus below the nominal power. The dashed line curves are below the bold line curve. Depletion can give rise to power variations of as much as 20 dB or more relative to the nominal power of the channels.

The third zone extends towards the end of the available bandwidth, and in the example shown up to an upper limit of 1700 nm. It covers a wavelength range of about 13 THz or 85 nm, and more generally a range having a width of 13 THz to 21 THz, i.e. about 70 nm to 120 nm. In this third zone, the channels of a multiplex are enriched by the previously mentioned channels, and thus present power that is higher than the expected nominal power. The power difference relative to the nominal power can be as much 20 dB or even more.

The second zone extends between the first and third zones. In this second zone, the signals of the channels in the multiplex are enriched by energy transferred by the Raman effect coming from the preceding channels. The channels of the multiplex are also depleted by energy transfer by the Raman effect towards the following channels. When both of these factors are taken into account, the power in the channels in the second zone is less affected by the Raman effect. This remains true providing conditions are not reached that are so unbalanced as to cause oscillations to appear in the spectral distribution of power. Such conditions are unlikely in a system presenting the proposed compensation in the first and third zones, particularly if the compensation means include distributed amplification at the shorter wavelengths or distributed loss at the longer wavelengths, and even more particularly if it includes both of these two compensation means.

The two dashed line curves in Figure 1 represent different approximations to the distortions induced by the Raman effect; these distortions are a function in particular of the total injected power, of the bandwidth, of the attenuation, of the effective sectional area, of the composition, and of the length of the fiber.

As mentioned above, it is found that the distortions induced by the Raman effect over a very broad band are quite different from the simple tilting mentioned in the above-cited article by S. Bigo et al. By way of example, Figure 1 shows a wavelength bandwidth of 500 nm. It is clear that a curve of similar appearance can be found over narrower bands, e.g. having a width of around 250 nm or 300 nm. The use of two distinct and separate bands, e.g. one band around 1.3 μm and another band around 1.55 μm does not lead to distortion of the type shown in Figure 1, but merely to distortion of the kind described in the state of the art. If channels are added between 1.3 μm and 1.55 μm, e.g. channels in the range 1.4 μm to 1.5 μm or in the range 1.6 μm to 1.7 μm, then distortion will be found having the appearance of Figure 1. This is due to the fact that having a gap between bands of more than about 20 THz eliminates the incidence of the Raman effect; this effect is at its maximum between bands that are about 13 THz apart.

The invention relies on the observation that this distortion is different from the distortion described in the articles of the state of the art. The invention proposes compensating this distortion so as to make transmission possible. Figure 2 is a diagrammatic graph showing the appearance of gain for amplification in a very broad band transmission system. Wavelength in the range 1200 nm to 1700 nm (or 250 THz to 175 THz) is plotted along the abscissa and proposed gain is plotted up the ordinate. The continuous line represents average amplification corresponding to amplification in the above identified second zone. This is the amplification that

would be required if there was no energy transfer due to the Raman effect. The dashed lines shows the appearance of the amplification gain proposed in the invention in order to compensate for the Raman effect distortion.

As shown in the figure, in the first above-identified zone, gain is greater than the average gain and it decreases in substantially linear manner. Its initial value is about 20 dB greater than the average gain and its value decreases progressively until it reaches average gain after about 13 THz to 21 THz. The gain thus compensates for the depletion in those channels that lie in the first zone. In this zone, the invention thus proposes using amplifiers presenting gain that is much greater than the average gain. The slope of these amplifiers is given in Figure 2, and it can be as much as 20 dB over 80 nm, i.e. about 0.25 dB/nm.

For gain compensation in this first zone, it is advantageous to use distributed amplifiers, e.g. Raman amplifiers. This embodiment relaxes the constraints that need to be imposed on discrete amplifiers for achieving the proposed levels of amplification. In addition, the use of distributed amplifiers over this first zone makes it possible to limit the power used, in particular in comparison with a solution using discrete amplifiers. Such a limit on the level of power that can be injected reduces the distortion induced by the Raman effect.

In the above-defined third zone, gain is less than the average gain. It decreases in a manner that is also substantially linear. The drop in gain thus compensates for the enrichment of the channels in the third zone. As shown in dashed lines in Figure 1, this enrichment can give rise to oscillations and can result in an excessive consumption of energy. The invention proposes imposing conditions on the longer wavelengths that make it possible to avoid enrichment and to limit such oscillations. In a first embodiment, the invention proposes using powers in this third zone which are at

lower level than in the remainder of the band, and that require less amplification. This further decreases the constraints on the amplifiers acting in this zone, whether discrete or distributed. Another solution, which does not exclude the first, consists in extending the transmission window to wavelengths beyond 1620 nm or indeed 1650 nm or even 1670 nm, and in using the increasing linear losses of the transmission fiber to compensate for the distortion induced by the Raman effect. This solution makes it possible in particular to use existing optical fibers for transmission over wavelength bands that were previously believed to be unusable, and for example to use conventional G.652 fibers at wavelengths going up to 1650 nm or 1680 nm or even 1700 nm or beyond. It is also possible to use attenuators in this third zone.

In the second zone, the required variations in gain are small and gain is substantially equal to average gain. It is possible in this zone to use amplifiers having gain that is substantially flat, of the same kind as the amplifiers commonly used in narrow band transmission systems.

The invention thus makes it possible to compensate for the distortion induced by the Raman effect on the channels in a very broad band transmission system.

The invention also proposes other solutions, which combined with the above-described compensation, can make it possible to limit the distortion caused by the Raman effect. In one embodiment, the invention proposes using low powers in the transmission system so as to limit energy transfers by the Raman effect. The optimum power per channel in a very broad band WDM system suffering from Raman crosstalk, particularly if not compensated by other means, is lower than the optimum power that would be appropriate in the absence of this phenomenon (transmission in a narrow band) since it is a non-linear effect. Energy transfers between channels are

proportional to the product of the powers in both channels. The use of distributed amplification in the low end of the band also serves to limit power. As shown for smaller bandwidths in the above-cited article by N. Zirngibl, Raman effect crosstalk depends on the total power injected into the fiber. Smaller total power can serve to limit the distortion caused by the Raman effect.

It is also possible to manage the transmission system when traffic is low, i.e. when traffic is below the maximum traffic that can be accepted by the transmission system. Switching off channels that are unused because of the small amount of payload traffic would significantly modify the effects of Raman gain. Although it is indeed possible, such a solution is not preferred and the invention proposes continuing to emit over channels that are lightly loaded, possibly by emitting at lower data rates, and while making sure to use signals that are decorrelated between the various channels. This solution implying the use of loading signals has the advantage of conserving the load on the optical amplifiers and the form of the distortion to be compensated.

The invention thus also provides a very broad band optical amplifier or amplification system for compensating the distortion induced by the Raman effect. The amplification system can comprise an amplifier or a combination of amplifiers having narrower individual bandwidths. For short wavelengths, the amplification system can have amplification means with gain greater than the average gain; in particular it can have distributed amplification means. At long wavelengths, the amplification system can present amplification means with gain that is lower than the average gain.

It is clear that the compensation means described above can compensate for all of the Raman effect energy transfer or can compensate said energy transfer in part only. In particular, total compensation over all of the

channels is not always necessary in all transmission systems. The invention is thus not restricted only to providing total compensation over the entire bandwidth under consideration.

Naturally, the present invention is not limited to the examples and embodiments described and shown, but it can be modified in numerous ways by the person skilled in the art. The ranges of wavelengths proposed in the figures are given by way of example only, and the invention applies to all very broad band transmission systems. The amplification means can comprise amplifiers that are discrete or distributed, and the number of amplifiers can vary depending on the application. For distributed Raman type amplification, the Raman amplification can be co- or contra-directional, or both together. In other words, the pump beams can be injected in the signal propagation direction, or in the opposite direction, or simultaneously in both directions. Co-directional amplification is more effective than contra-directional amplification for reducing the effect of Raman crosstalk. Nevertheless it suffers from other drawbacks and as a result it is generally accepted outside the context of the invention that a contra-directional amplification scheme is preferable when using distributed Raman amplification.

In the embodiments descried above, the distributed amplification is Raman amplification. The amplification is not necessarily entirely Raman amplification, and it could equally well be completely or partially constituted by distributed or discrete rare earth amplification. Nevertheless, Raman amplification is preferred in this context in the above-mentioned first zone since it makes it possible to implement an average tilt and to adjust its slope and shape over any range of wavelengths, by an appropriate choice of pumping wavelengths. In contrast, it is difficult to match the various parameters when using rare earth amplification. In any event, it is

possible to use Raman amplification, rare earth amplification, or any combination of both in each of the above-defined zones. The amplification can be discrete (i.e. localized) or it can be distributed, or these two modes can be combined.

In the examples given above, consideration is given to transmission over a wavelength bandwidth of 500 nm. Nevertheless, the invention is also applicable to narrower wavelength bandwidths, e.g. bandwidths of about 150 nm or about 20 THz, around 1550 nm. Over such narrower wavelength bands, the solutions proposed in the prior art are not capable of compensating Raman gain totally or partially over the entire bandwidth in question.

In the embodiments described, Raman gain effect compensation is applied to a very broad band transmission system, both at the low end of the band by using amplification and at the high end of the band by using attenuation. This solution also applies to systems which are not very broad band, e.g. systems having a bandwidth of less than 20 THz. Under such circumstances, this dual compensation provides better equalization, and also makes it possible to limit the power used in the shorter wavelength pumps. Compared with a solution involving attenuation over the entire bandwidth, this dual compensation limits total losses in the channels at the shorter wavelengths.

CLAIMS

1/ A very broad band wavelength division multiplexed transmission system with means for compensating energy transfers between channels caused by the Raman effect.

2/ The system of claim 1, characterized by a bandwidth greater than 20 THz.

3/ The system of claim 1, characterized by a bandwidth greater than 30 THz.

4/ The system of claim 1, 2, or 3, characterized in that said band extends beyond 1620 nm, preferably beyond 1650 nm, or even more preferably beyond 1670 nm.

5/ The system of any one of claims 1 to 4, characterized in that the compensation means compensate depletion in channels over the beginning of the band.

6/ The system of claim 5, characterized in that the compensation means compensate depletion in the channels at the beginning of the band over a bandwidth lying in the range 13 THz to 21 THz.

7/ The system of any one of claims 1 to 6, characterized in that the compensation means compensate enrichment of channels over the end of the band.

8/ The system of claim 7, characterized in that the compensation means compensate enrichment of the channels over the end of the band over a bandwidth lying in the range 13 THz to 21 THz.

9/ The system of claim 7 or claim 8, characterized in that the compensation means compensate enrichment of the channels over the end of the band by linear losses in the fiber of the transmission system.

10/ The system of claim 7, 8, or 9, characterized in that the compensation means comprise means for emitting lower powers over the end of the band.

11/ A very broad band optical amplification system comprising compensation means for compensating energy transfers caused by the Raman effect.

12/ The system of claim 11, characterized by a bandwidth greater than 20 THz.

13/ The system of claim 11, characterized by a bandwidth greater than 30 THz.

14/ The system of claim 11, 12, or 13, characterized in that the compensation means compensate depletion in the channels over the beginning of the band.

15/ The system of claim 14, characterized in that the compensation means compensate depletion in the channels over the beginning of the band over a bandwidth lying in the range 13 THz to 21 THz.

16/ The system of claim 14 or claim 15, characterized in that it comprises distributed amplification means over the beginning of the band.

17/ The system of claim 16, characterized in that the distributed amplification means comprise Raman amplification means.

18/ The system of claim 16 or claim 17, characterized in that the distributed amplification means comprise rare earth amplification means.

19/ The system of any one of claims 11 to 18, characterized in that the compensation means compensate enrichment of the channels over the end of the band.

20/ The system of claim 19, characterized in that the compensation means compensate enrichment of the channels over the end of the band over a bandwidth lying in the range 13 THz to 21 THz.

A B S T R A C T

AMPLIFICATION FOR VERY BROAD BAND OPTICAL FIBER TRANSMISSION SYSTEMS

The invention relates to a very broad band wavelength multiplexed transmission system, typically having a bandwidth greater than 150 nm or 200 nm, and in which energy transfers between channels caused by the Raman effect are compensated. The depletion of channels at shorter wavelengths is compensated by amplification which is preferably distributed, while the enrichment of channels at longer wavelengths is compensated by attenuation.

Translation of the title and the abstract as they were when originally filed by the Applicant. No account has been taken of any changes that may have been made subsequently by the PCT Authorities acting ex officio, e.g. under PCT Rules 37.2, 38.2, and/or 48.3.

09/856362

Figure 1

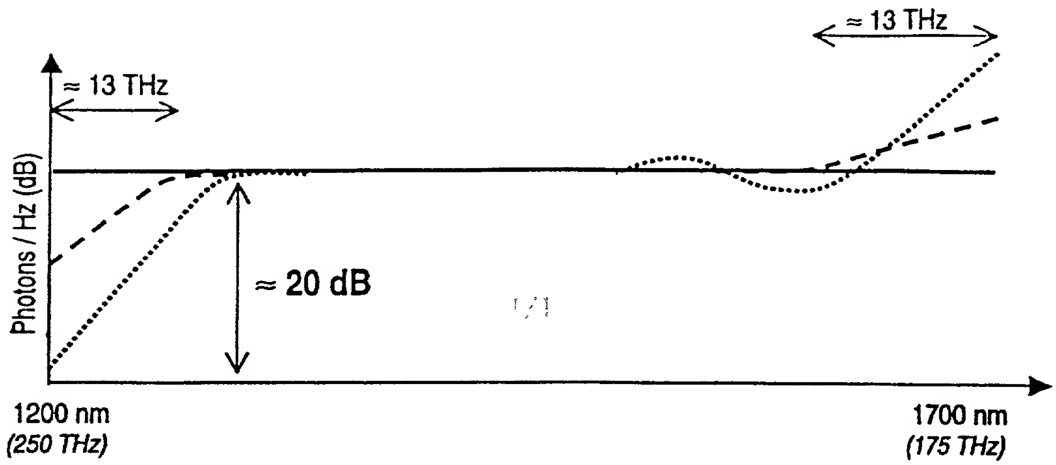
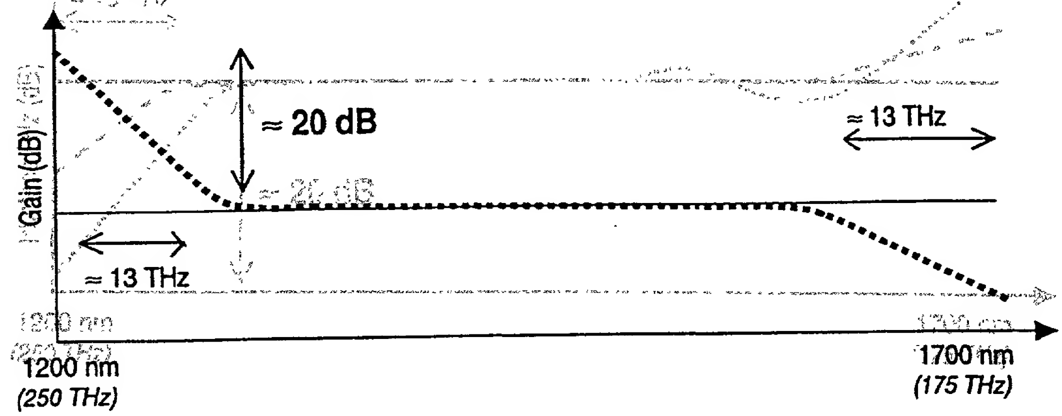


Figure 2



Declaration and Power of Attorney for Patent Application

Déclaration et Pouvoirs pour Demande de Brevet

French Language Declaration

En tant que l'inventeur nommé ci-après, je déclare par le présent acte que:

As a below named inventor, I hereby declare that:

Mon domicile, mon adresse postale et ma nationalité sont ceux figurant ci-dessous à côté de mon nom.

My residence, post office address and citizenship are as stated next to my name.

Je crois être le premier inventeur original et unique (si un seul nom est mentionné ci-dessous), ou l'un des premiers co-inventeurs originaux (si plusieurs noms sont mentionnés ci-dessous) de l'objet revendiqué, pour lequel une demande de brevet a été déposée concernant l'invention de la description identifiée par le numéro de référence

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention in the specification identified by Docket No.

102224/LA/OOC D

Je déclare par le présent acte avoir passé en revue et compris le contenu de la description ci-dessus, revendications comprises.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims.

Je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

Je revendique par le présent acte avoir la priorité étrangere, en vertu du Titre 35, § 119(a)-(d) ou § 365(b) du Code des Etats-Unis, sur toute demande étrangère de brevet ou certificat d'inventeur ou, en vertu du Titre 35, § 365(a) du même Code, sur toute demande internationale PCT désignant au moins un pays autre que les Etats-Unis et figurant ci-dessous et, j'ai aussi indiqué ci-dessous toute demande étrangère de brevet, tout certificat d'inventeur ou toute demande internationale PCT ayant une date de dépôt précédant celle de la demande à propos de laquelle une priorité est revendiquée.

I hereby claim foreign priority under Title 35, United States Code, § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below, and have also identified below any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior foreign application(s) for which priority is claimed
Demande(s) de brevet étrangère(s) antérieure(s) dont la priorité est revendiquée

(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)
99 11 875	FRANCE	23 SEPTEMBER 1999

Prior foreign applications for which priority is not claimed
Demande(s) de brevet étrangères antérieure(s) dont la priorité n'est pas revendiquée

(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)

French Language Declaration

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 119(e) du Code des Etats-Unis, de toute demande de brevet provisoire effectuée aux Etats-Unis et figurant ci-dessous.

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

(Application No.)
(No de demande)

(Filing Date)
(Date de dépôt)

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 120 du Code des Etats-Unis, de toute demande de brevet effectuée aux Etats-Unis, ou en vertu du Titre 35, § 365(c) du même Code, de toute demande internationale PCT désignant les Etats-Unis et figurant ci-dessous et, dans la mesure où l'objet de chacune des revendications de cette demande de brevet n'est pas divulgué dans la demande antérieure américaine ou internationale PCT, en vertu des dispositions du premier paragraphe du Titre 35, § 112 du Code des Etats-Unis, je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations, dont j'ai pu disposer entre la date de dépôt de la demande antérieure et la date de dépôt de la demande nationale ou internationale PCT de la présente demande.

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

(Application No.)
(N0 de demande)

(Filing Date)
(Date de dépôt)

(Status)(patented, pending, abandoned)
(Statut)(breveté, en cours d'examen, abandonné)

Je déclare par le présent acte que toute déclaration ci-incluse est, à ma connaissance, véridique et que toute déclaration formulée à partir de renseignements ou de suppositions est tenue pour véridique; et de plus, que toutes ces déclarations ont été formulées en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d'une incarcération, ou des deux, en vertu de la Section 1001 du Titre 18 du Code des Etats-Unis, et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

31

POUVOIRS: En tant que l'inventeur cité, je désigne par la présente l'(les) avocat(s) et/ou agent(s) suivant(s) pour qu'ils poursuive(nt) la procédure de cette demande de brevet et traite(nt) toute affaire s'y rapportant avec l'Office des brevets et des marques: (mentionner le nom et le numéro d'enregistrement).

POWER OF ATTORNEY. As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: (list name and registration number)

John H. Mion, Reg. No. 18,879; Thomas J. Macpeak, Reg. No. 19,292; Robert J. Seas, Jr., Reg. No. 21,092; Darryl Mexic, Reg. No. 23,063; Robert V. Sloan, Reg. No. 22,775; Peter D. Olexy, Reg. No. 24,513; J. Frank Osha, Reg. No. 24,625; Waddell A. Biggart, Reg. No. 24,861; Louis Gubinsky, Reg. No. 24,835; Neil B. Siegel, Reg. No. 25,200; David J. Cushing, Reg. No. 28,703; John R. Inge, Reg. No. 26,916; Joseph J. Ruch, Jr., Reg. No. 26,577; Sheldon I. Landsman, Reg. No. 25,430; Richard C. Turner, Reg. No. 29,710; Howard L. Bernstein, Reg. No. 25,665; Alan J. Kasper, Reg. No 25,426; Kenneth J. Burchfiel, Reg. No. 31,333; Gordon Kit, Reg. No 30,764; Susan J. Mack, Reg. No. 30,951; Frank L. Bernstein, Reg. No. 31,484, Mark Boland, Reg. No. 32,197; William H. Mandir, Reg. No. 32,156; Scott M. Daniels, Reg. No. 32,562; Brian W. Hannon, Reg. No. 32,778; Abraham J. Rosner, Reg. No. 33,276; Bruce E. Kramer, Reg. No 33,725; Paul F. Neils, Reg. No. 33,102; and Brett S. Sylvester, Reg. No. 32,765; and Robert M. Masters, Reg. No. 35,603.

Adresser toute correspondance à:

Send Correspondence to:
SUGHRUE, MION, ZINN, MACPEAK & SEAS, PLLC
2100 Pennsylvania Avenue, N.W., Suite 800
Washington, D.C. 20037-3213

Nom complet de l'unique ou premier inventeur 1-00	Full name of sole or first inventor (First Middle Last) Dominique HAMOIR
Signature de l'inventeur Date	Inventor's signature Hamoir Date 4 July 2000
Domicile	Residence ~~92120 MONTROUGE~~ 91620 NOZAY FRANCE FRX
Nationalité	Citizenship French
Adresse postale	Post Office Address ~~62, avenue de la République~~ 16, rue des Acacias ~~92120 MONTROUGE~~, FRANCE 91620 NOZAY, FR
Nom complet du second co-inventeur, le cas échéant	Full name of second joint inventor, if any (First Middle Last)
Signature du second inventeur Date	Second inventor's signature Date
Domicile	Residence
Nationalité	Citizenship
Adresse postale	Post Office Address

(Fournir les mêmes renseignements et la signature de tout co-inventeur supplémentaire.)

(Supply similar information and signature for third and subsequent joint inventors.)